JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
JENNIFER2
EU grant n.822070
Bundesministerium für Bildung und Forschung
ErUM-FSP T09 Belle II

Replacement talk on short notice
for Umberto Tamponi and Todd Peddlar

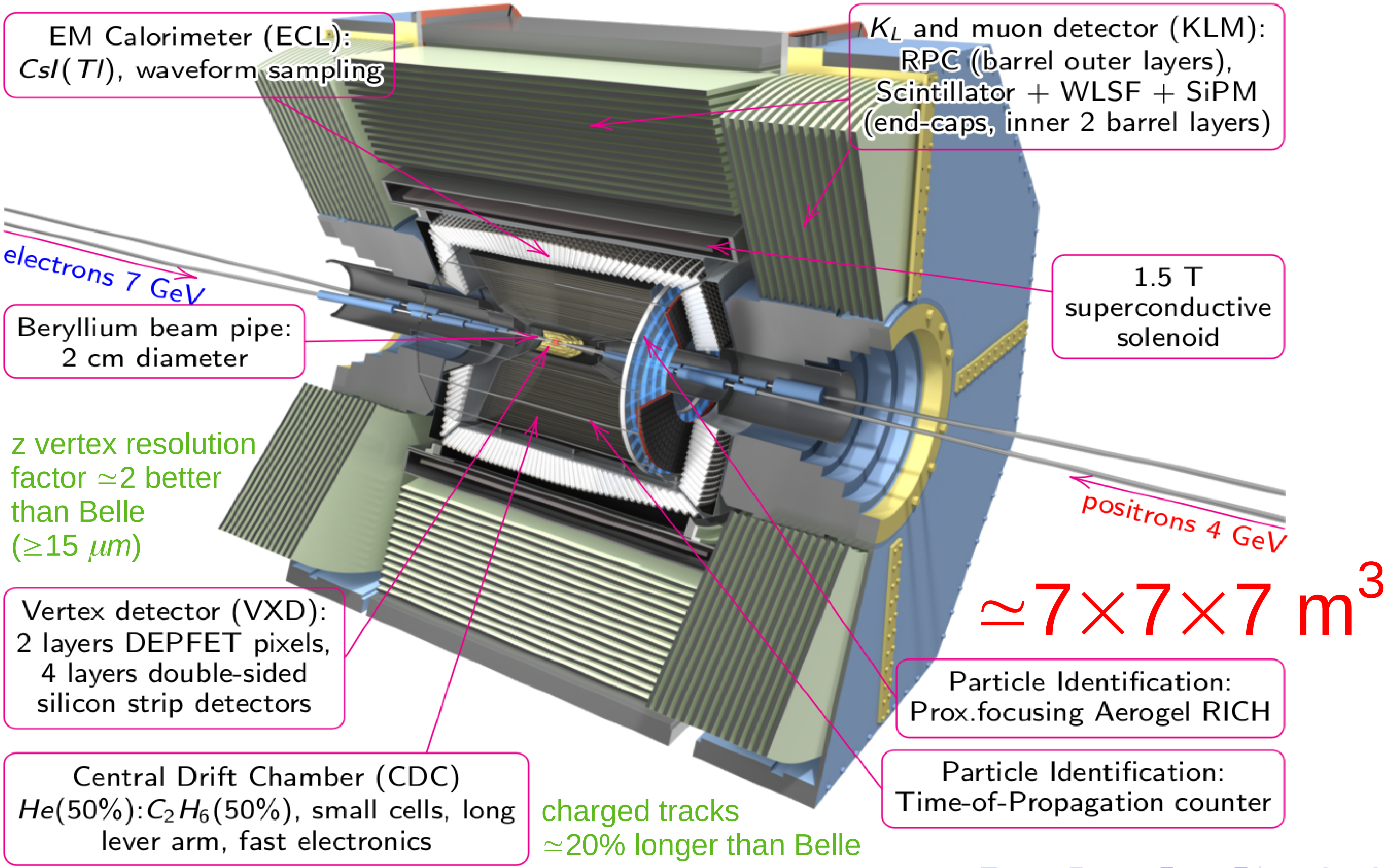
BELLE

Belle II

Bottomonium search at Belle and Belle II

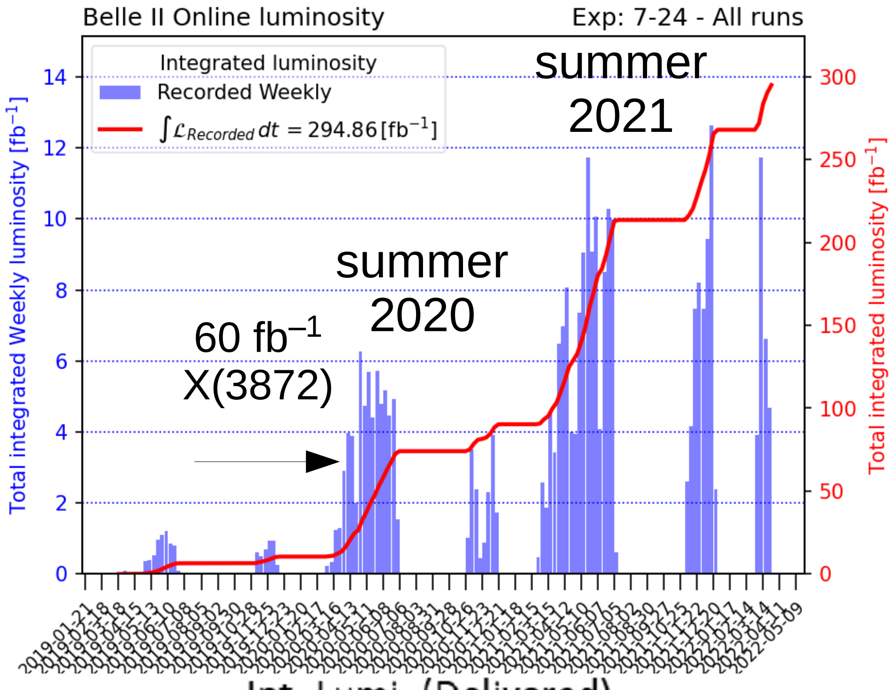
Elisabetta Prencipe, Jens Sören Lange
(Justus-Liebig-Universität Giessen)
MITP, 24.03.2022

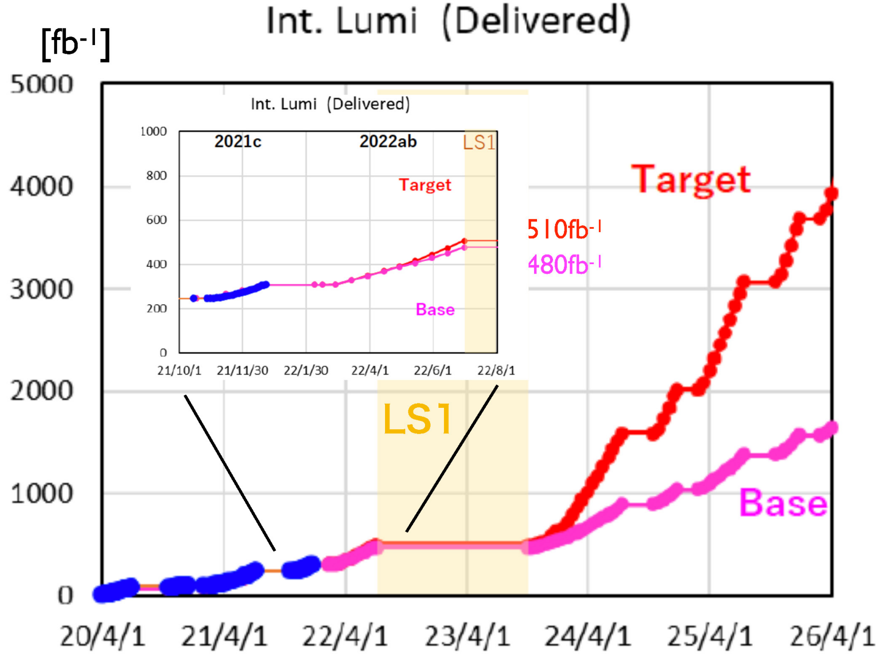
Belle II


EM Calorimeter (ECL):
$CsI(Tl)$, waveform sampling
K_L and muon detector (KLM):
RPC (barrel outer layers),
Scintillator + WLSF + SiPM
(end-caps, inner 2 barrel layers)
electrons 7 GeV
1.5 T
superconductive
solenoid
Beryllium beam pipe:
2 cm diameter
z vertex resolution
factor $\simeq$2 better
than Belle
($\geq$15 μm)
positrons 4 GeV
$\simeq 7 \times 7 \times 7\ \mathrm{m}^3$
Vertex detector (VXD):
2 layers DEPFET pixels,
4 layers double-sided
silicon strip detectors
Particle Identification:
Prox.focusing Aerogel RICH
Particle Identification:
Time-of-Propagation counter
Central Drift Chamber (CDC)
He(50%):C_2H_6(50%), small cells, long
lever arm, fast electronics
charged tracks
$\simeq$20% longer than Belle

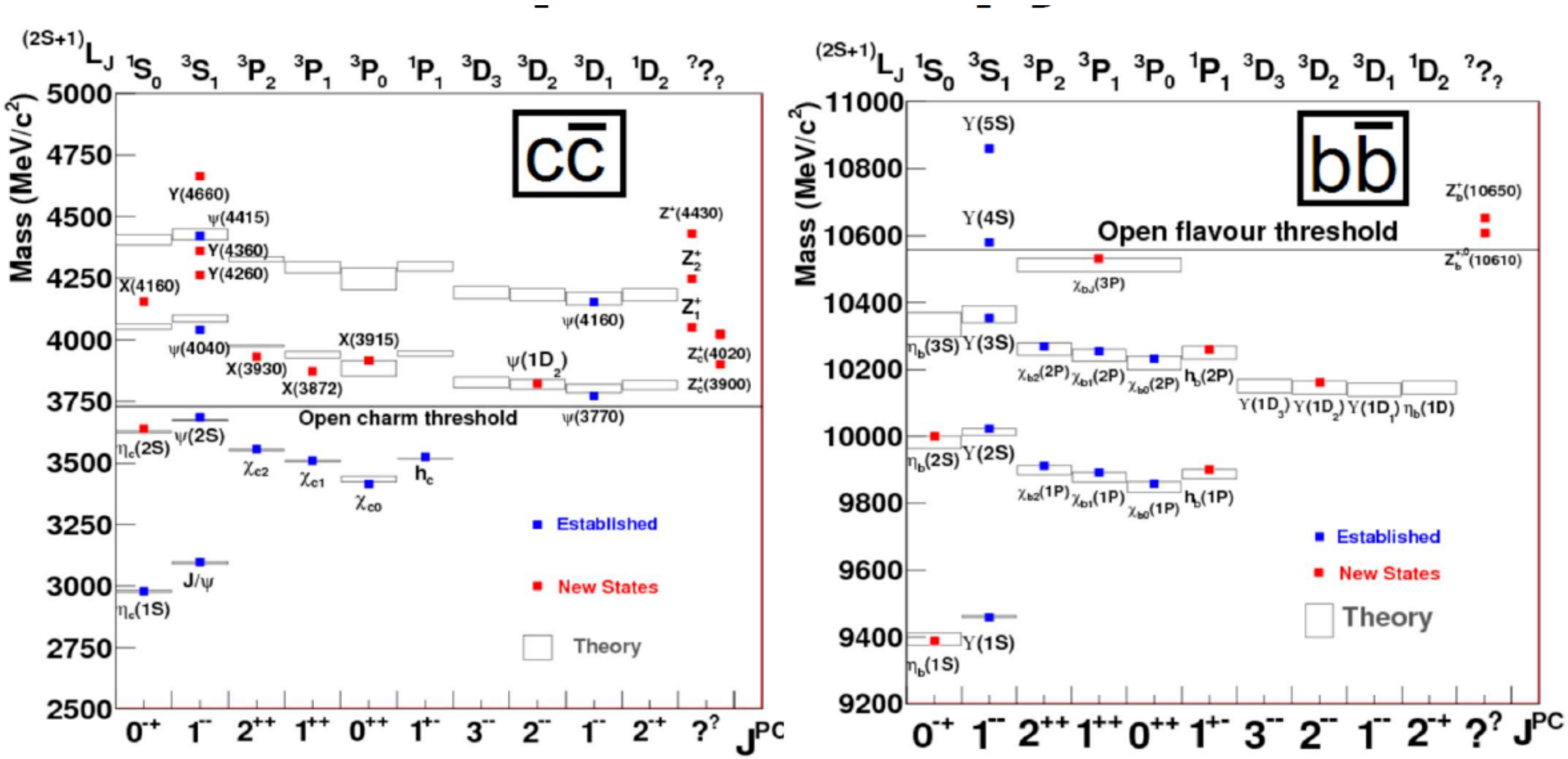
Status and plan of Belle II data taking

- Belle II collected data 295 fb^{-1} (~30% of Belle, ~55% of BaBar data) 1 fb^{-1} is about 1.1 Mill. $B\bar{B}$ pairs
- Peak luminosity reached $3.81 \times 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
  - 80% higher than previous world record by KEKB
  - Factor 3.81 higher than KEKB design luminosity
- 89.5% data taking efficiency during the pandemic situation (remote shifts & heroic local effort)
- Plan: long shutdown in 2023 (2nd layer of PXD, TOP upgrade)
- Plan: 50 ab^{-1} in ≥2031





How to access bottomonium



2P states and *D* state are <u>below</u> threshold

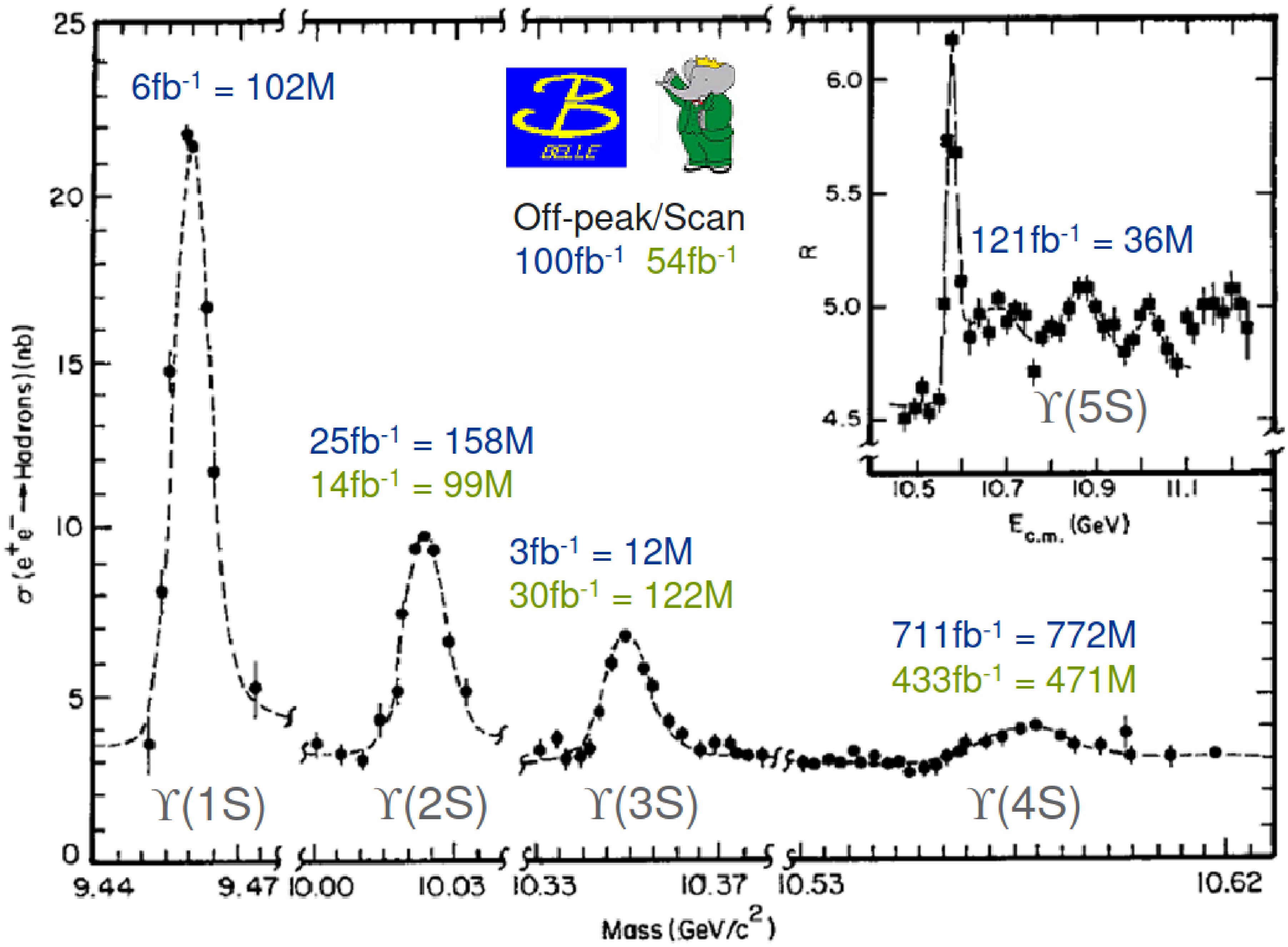
- Bottomonium is much less accessible than charmonium:

  - direct production in e^+e^- collision

  - prompt production

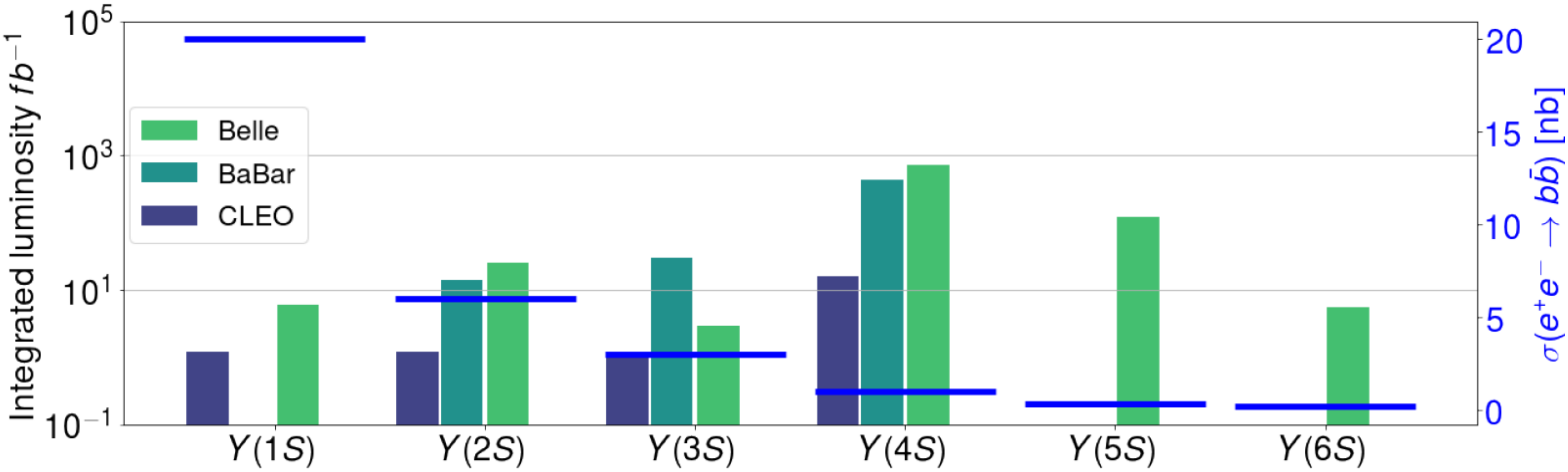
- Besides Belle II, only LHC experiments will produce bottomonia (with limitations)

BOTTOMONIUM PLANS AT BELLE II



25
20
15
10
5
0
σ (e+e− → Hadrons) (nb)
6fb-1 = 102M
25fb-1 = 158M
14fb-1 = 99M
3fb-1 = 12M
30fb-1 = 122M
711fb-1 = 772M
433fb-1 = 471M
Off-peak/Scan
100fb-1 54fb-1
BELLE
121fb-1 = 36M
6.0
5.5
5.0
4.5
R
10.5
10.7
10.9
11.1
Ec.m. (GeV)
ϒ(5S)
ϒ(1S)
ϒ(2S)
ϒ(3S)
ϒ(4S)
9.44
9.47
10.00
10.03
10.33
10.37
10.53
10.62
Mass (GeV/c2)

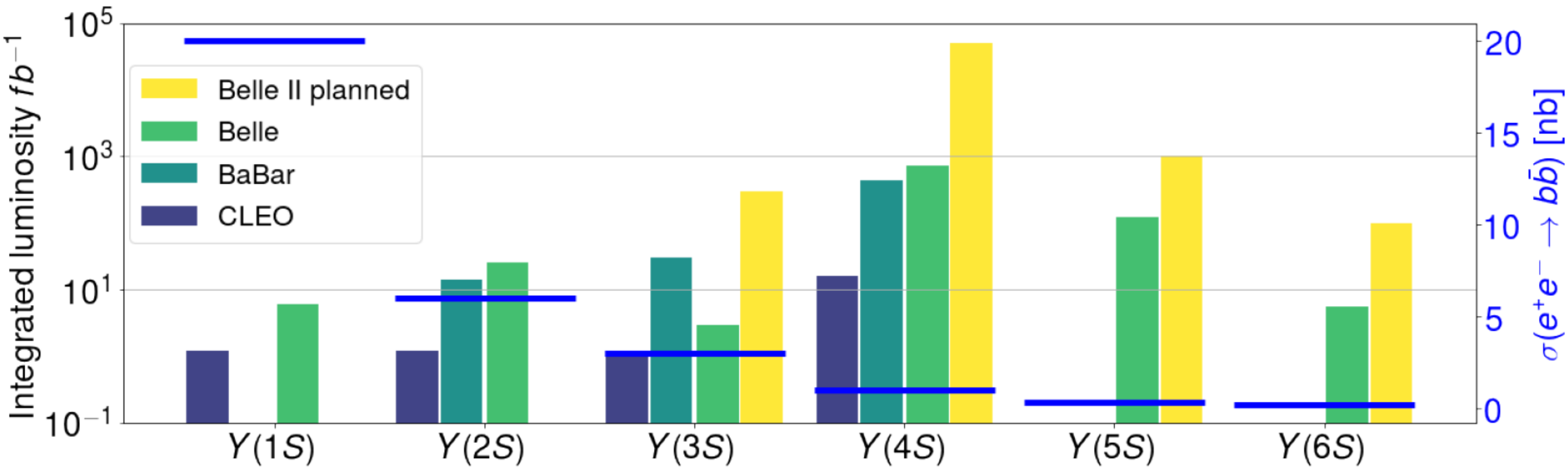
The Belle II bottomonium program



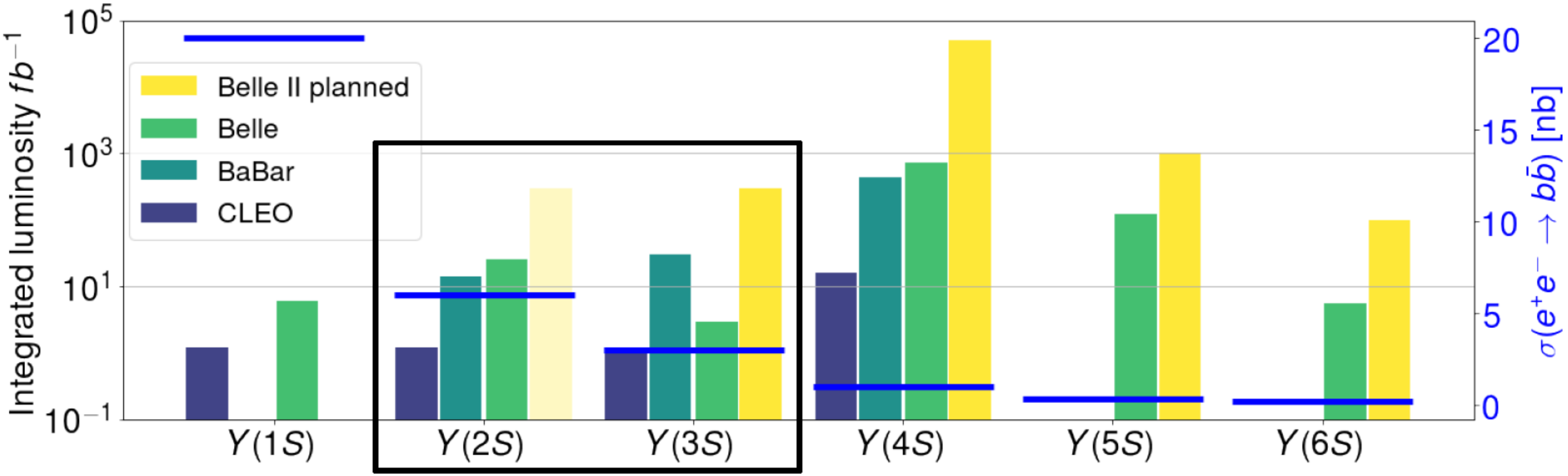
Only CLEO and Belle

Only Belle

The Belle II bottomonium program



The Belle II bottomonium program



300 fb^{-1} of Y(3S):

LFV, LUV, invisible decays

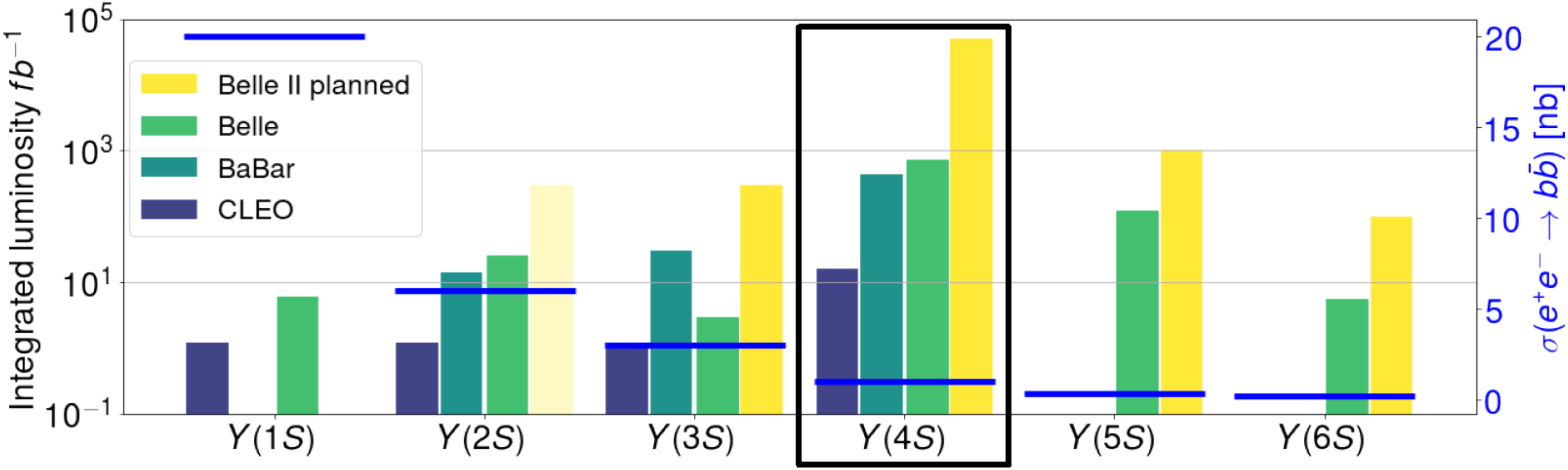
Deuteron formation by coalescence

Hyperons production and correlation

Charmonia and di-baryon exotica inclusive production

Precision QCD in radiative transitions

The Belle II bottomonium program



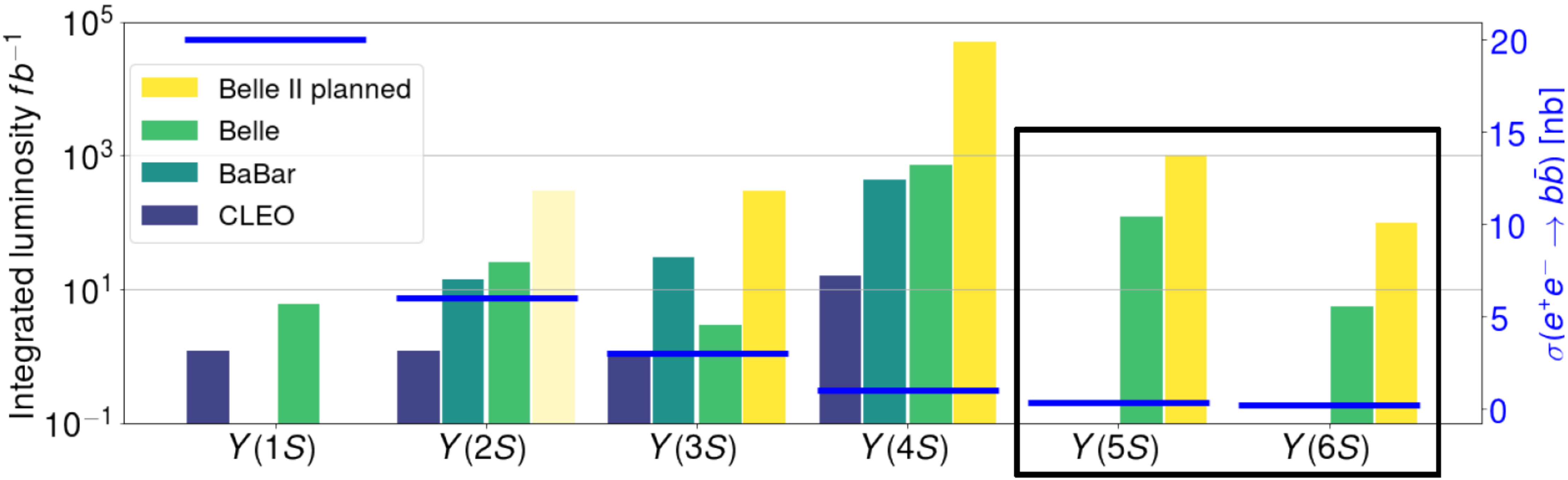
50 ab^{-1} of Υ(4S):

ISR

Precision spin-singlet spectroscopy

$\eta_b \to \gamma\gamma$!

The Belle II bottomonium program



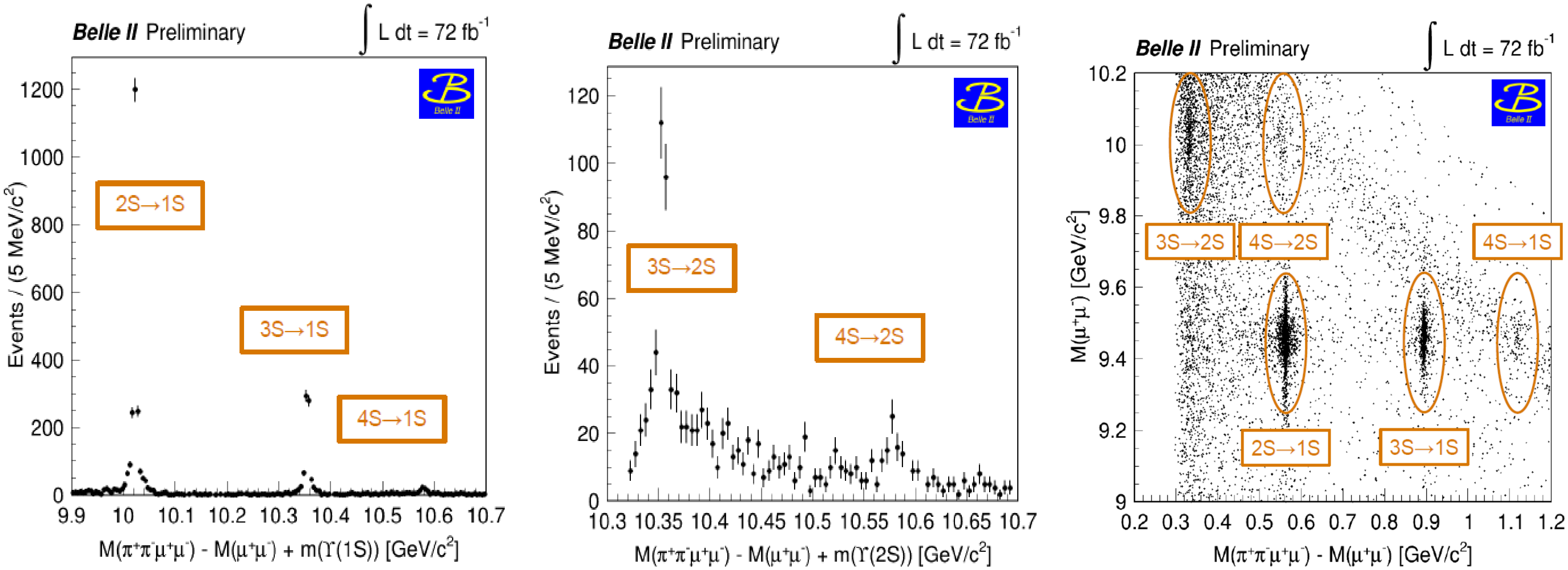
1+ ab^{-1} of Y(5S-6S): Exotica

Threshold exploration

Precision spin-singlet spectroscopy

High-statistics scan

First results on Υ(nS) transitions, Belle II data

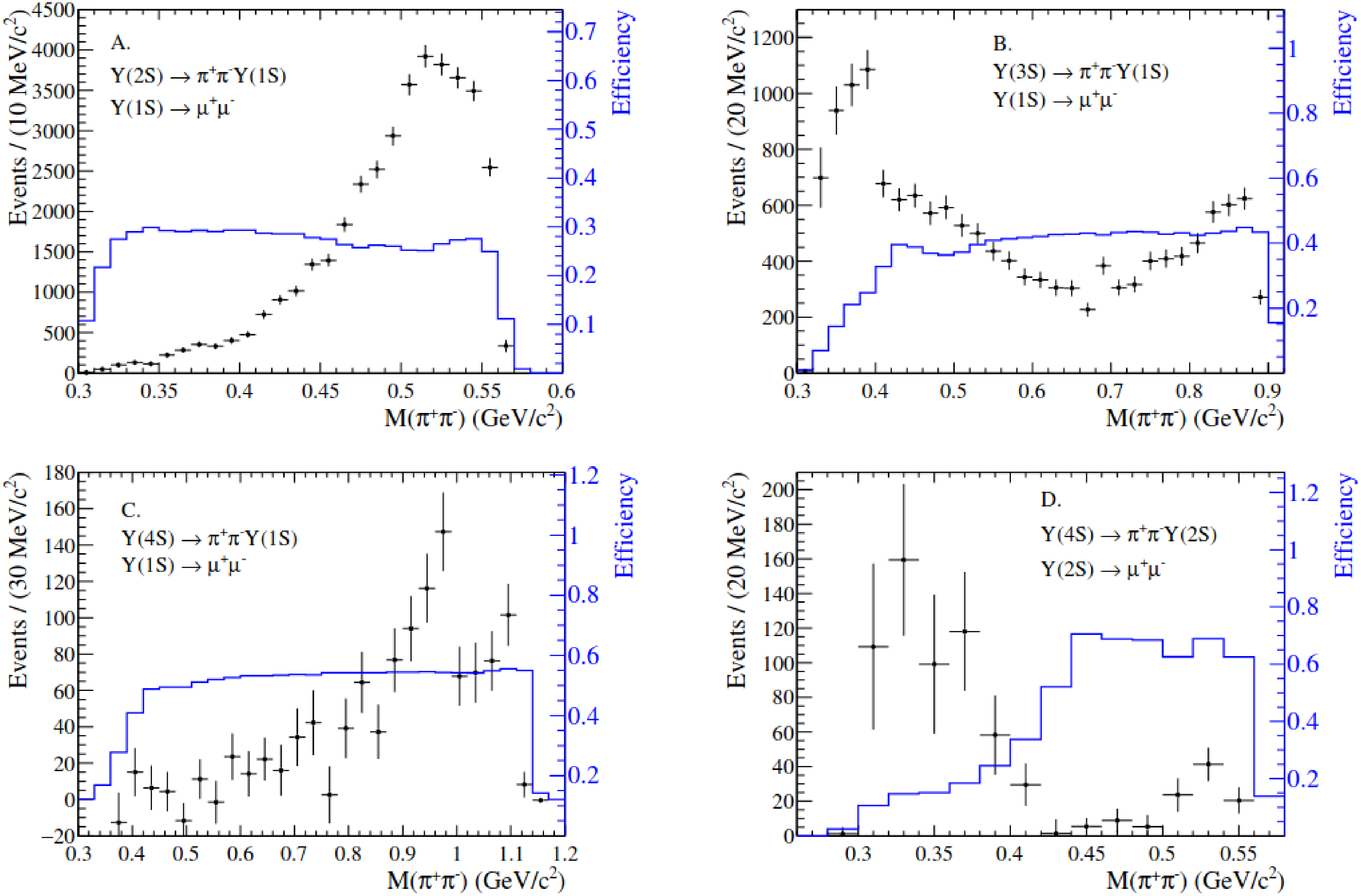


Two ways of production

- e+e– → Υ(nS) (adjusted by accelerator energies)
- Υ(nS) as final state in π+π– transitions

Bryan Fulsom, Talk at Hadron 2021

Dipion transitions

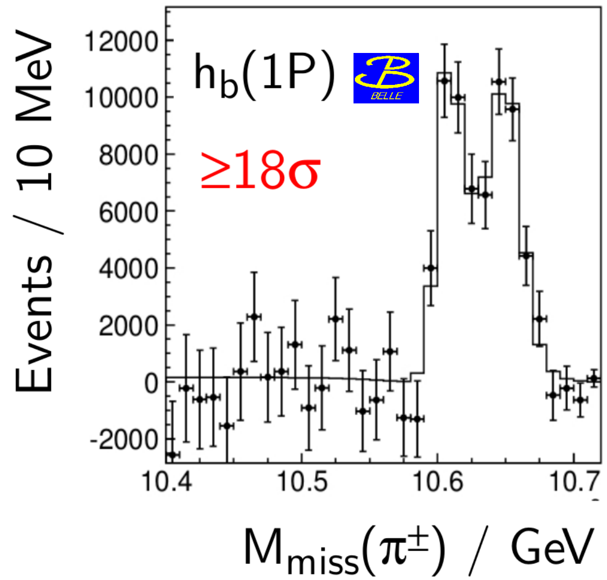


Belle, Phys. Rev. D 96 (2017) 052005

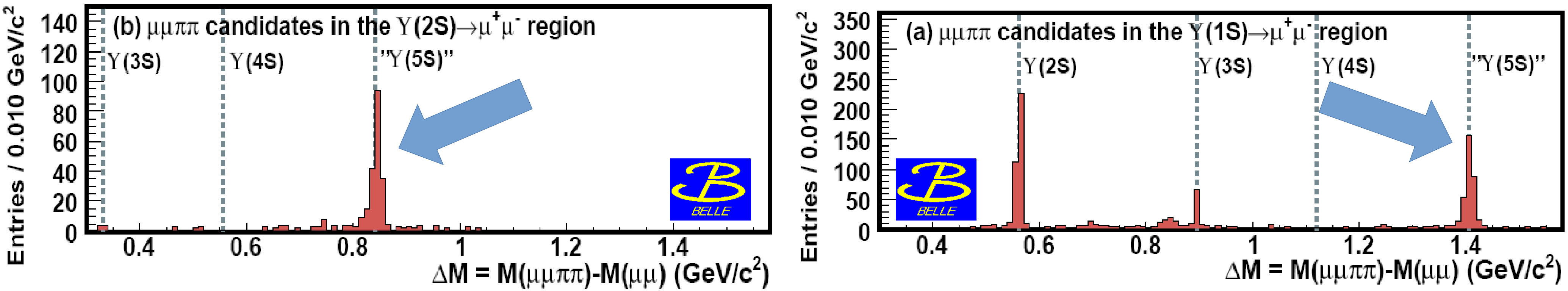
Y_b SCAN

BOTTOMONIUM

- $\Upsilon(5S)$ never observed at LHC
- Branching of $\Upsilon(5S)\to\Upsilon(nS)\pi\pi$ is factor $\simeq$1000 larger than $\Upsilon(4S)\to\Upsilon(nS)\pi\pi$ $\to\Upsilon(5S)$ exotic itself?
- Charged Z_b states observed in $\Upsilon(5S)$ decays
  Belle, Phys. Rev. D91 (2015) 072003
  (not seen at LHC either)
  peculiar properties:
  spin flip in decays not suppressed
- New state observed: $Y_b(10750)$



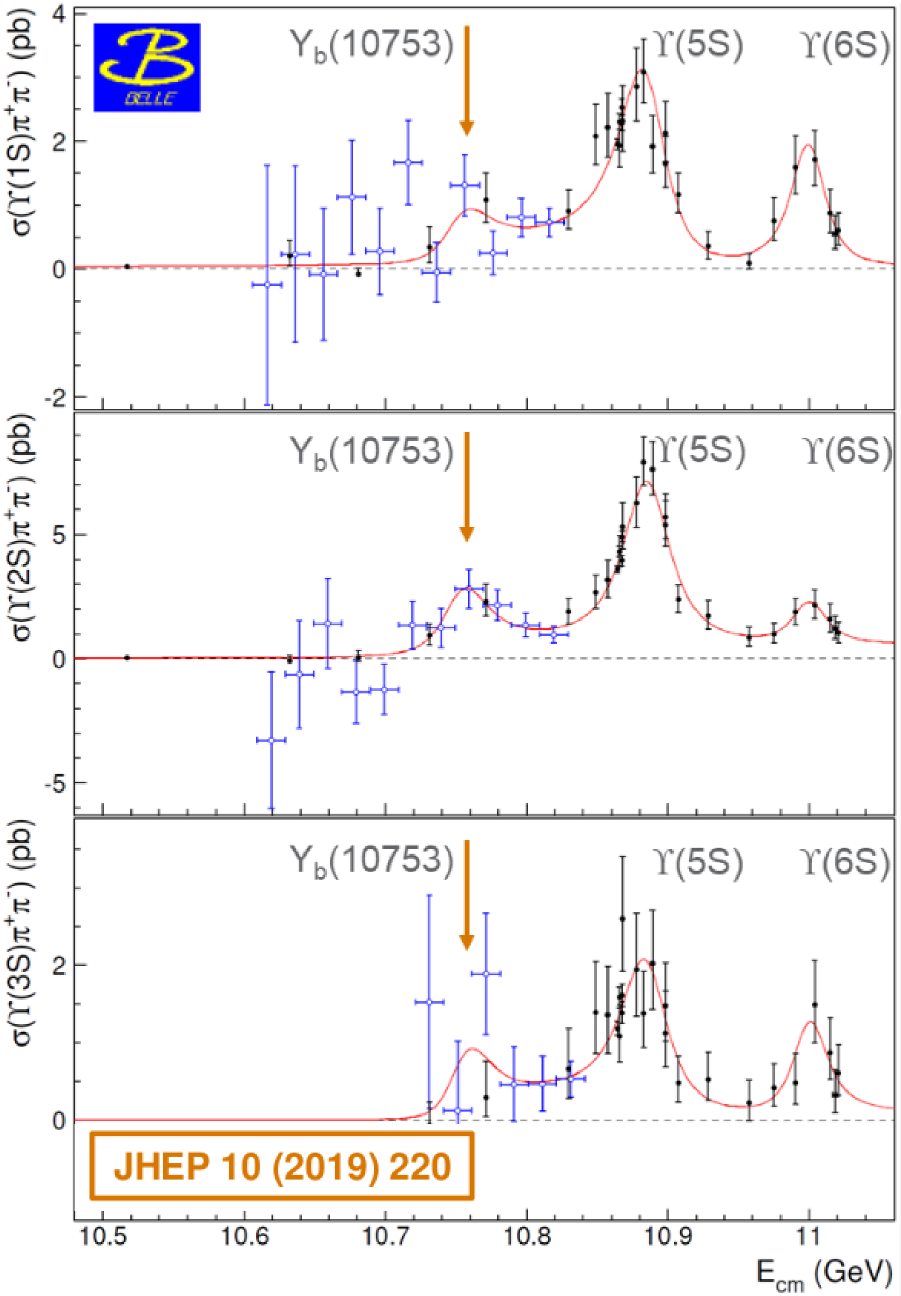
$Z_b(10610)^{\pm}$ m=10607.2±2.0 MeV
2.6 MeV above $\bar{B}B^*$ threshold
$Z_b'(10650)^{\pm}$ m=10652.2±1.5 MeV
2.0 MeV above $\bar{B}^*B^*$ threshold
confirmed in 5 decay modes



Belle Phys. Rev. Lett. 100, 112001 (2008)

$Y_b(10750)$

- Seven scan points below $\Upsilon(5S)$ at Belle, each $\simeq 1\ \mathrm{fb}^{-1}$
- New structure observed in $\Upsilon(nS)\pi\pi$



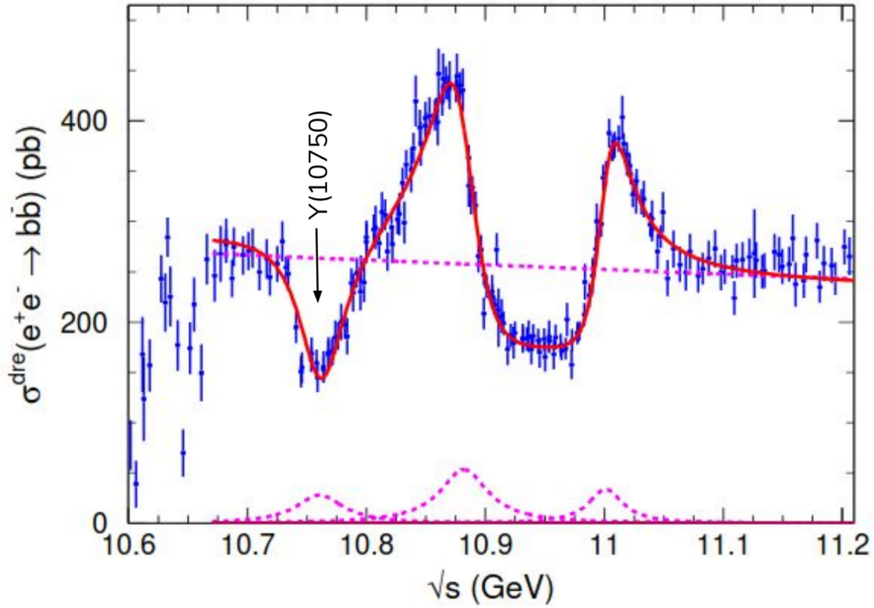
	$\Upsilon(10860)$	$\Upsilon(11020)$	New structure
M (MeV/c^2)	$10885.3 \pm 1.5\,^{+2.2}_{-0.9}$	$11000.0^{+4.0}_{-4.5}\,^{+1.0}_{-1.3}$	$10752.7 \pm 5.9\,^{+0.7}_{-1.1}$
Γ (MeV)	$36.6^{+4.5}_{-3.9}\,^{+0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8}\,^{+0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3}\,^{+3.9}_{-3.3}$

Further evidence in destructive interference

Refit of BaBar and Belle scan data

Dong et al., Chin. Phys. C 44 (2020) 8, 083001

Parameter	$Y(10750)$	$\Upsilon(5S)$	$\Upsilon(6S)$
Mass/(MeV/c^2)	10761 ± 2	10882 ± 1	11001 ± 1
Width/MeV	48.5 ± 3.0	49.5 ± 1.5	35.1 ± 1.2



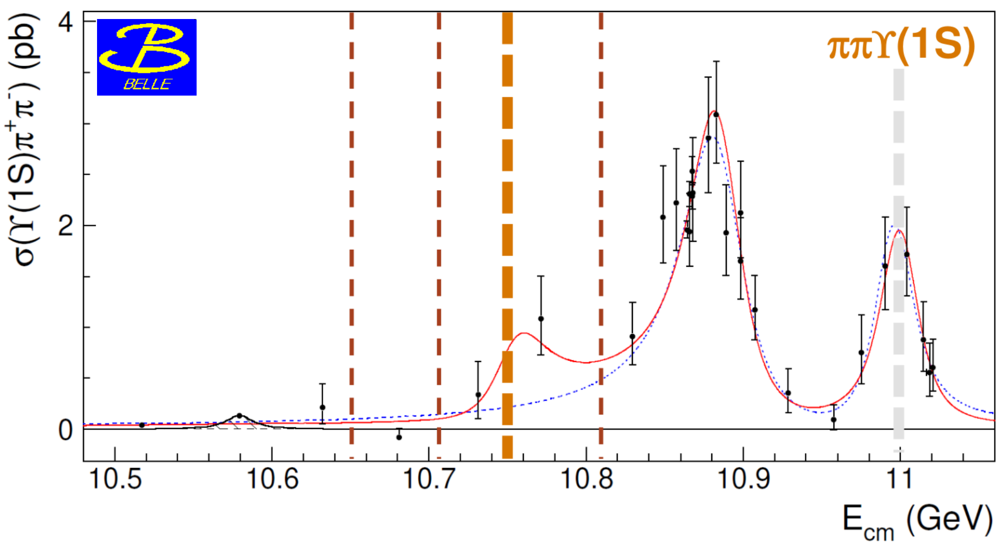
New Y_b Scan at Belle II (ongoing)

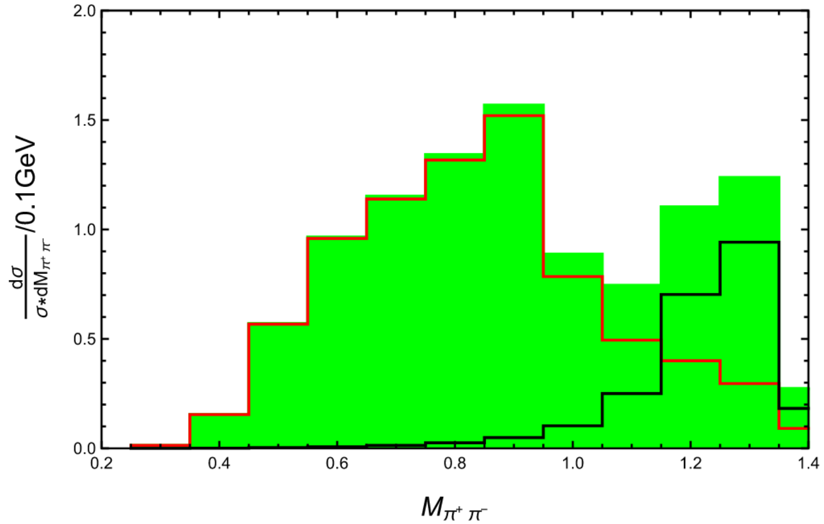
- Accelerator energies are changed
- Scan started 11.11.2021
- Prediction for $Y_b(10750) \to \Upsilon(1S)\pi\pi$

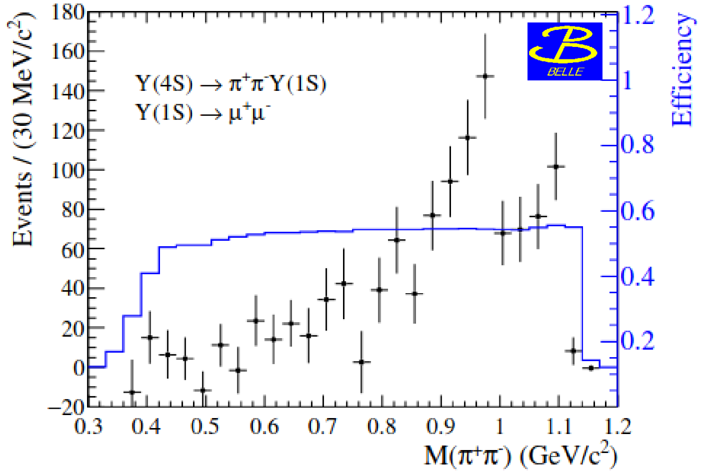
  Ali, Maiani, Parkhomenko, Wang,
  Phys. Lett. B 802 (2020) 135217

  - $\Upsilon(5S)$ decay is dominated by Z_b states but Y_b decay to Z_b suppressed/forbidden
  - $\pi\pi$ Mass distribution: tetraquark should have strong contribution from scalar f_0 states

Energy	Int. Luminosity
10.751 GeV	$\simeq 10\ fb^{-}1$
10.657	$\simeq 1\ fb^{-}1$
10.706	$\simeq 1\ fb^{-}1$ Plan
10.810	$\simeq 1\ fb^{-}1$







Belle, Phys. Rev. D96 (2017) 052005

New Y_b Scan at Belle II (ongoing) – $B\bar{B}$ decomposition

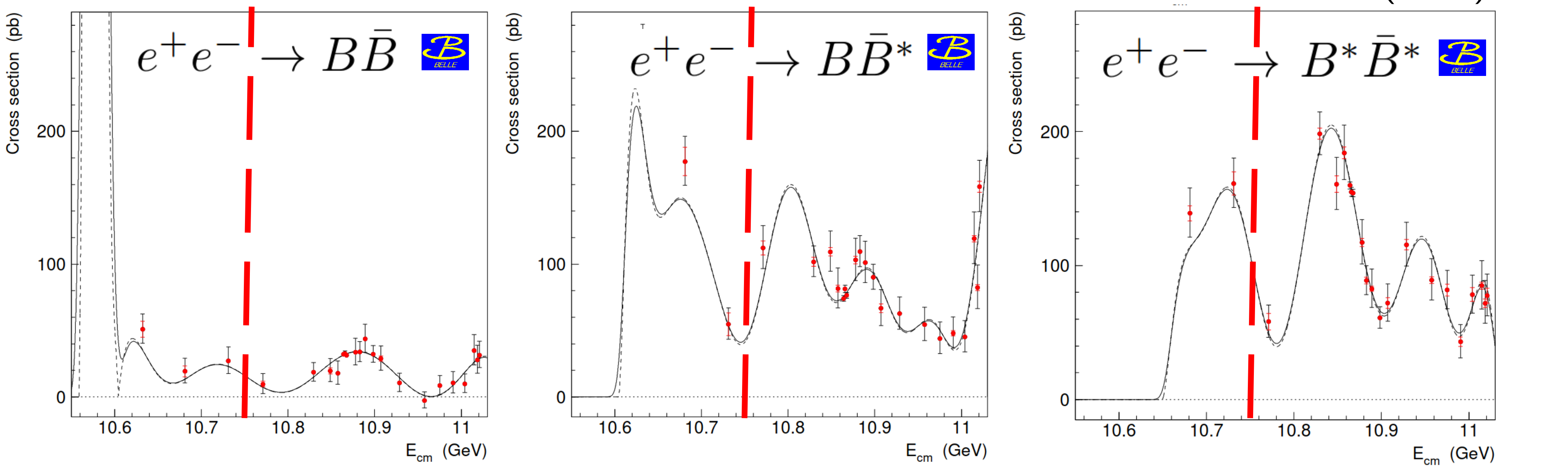
$q\bar{q}$ pair is present in the system

$q\bar{q}$ pair is created from vacuum
$^3P_0$ model

Mode	$\mathcal{B}(4q)$ (%)	$\mathcal{B}(b\bar{b})$ (%)	Heavy Quark Spin Symmetry
$B\bar{B}$	$39.3^{+38.7}_{-22.9}$	21.3	1
$B\bar{B}^*$	$\sim$0.2	14.3	4
$B^*\bar{B}^*$	$52.3^{+54.9}_{-31.7}$	64.1	7
$B_s\bar{B}_s$	-	0.3	

Liang et al., Phys. Lett B 803 (2020) 135340

Belle, JHEP 2106 (2021) 137

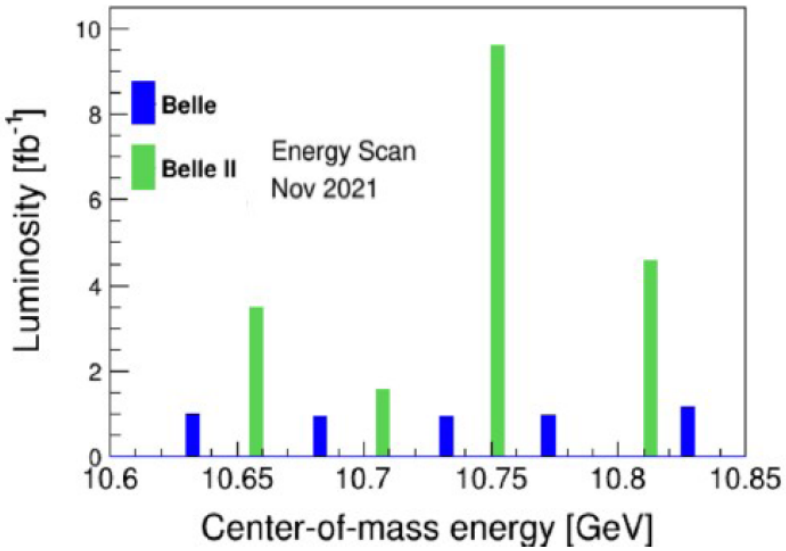


Summary

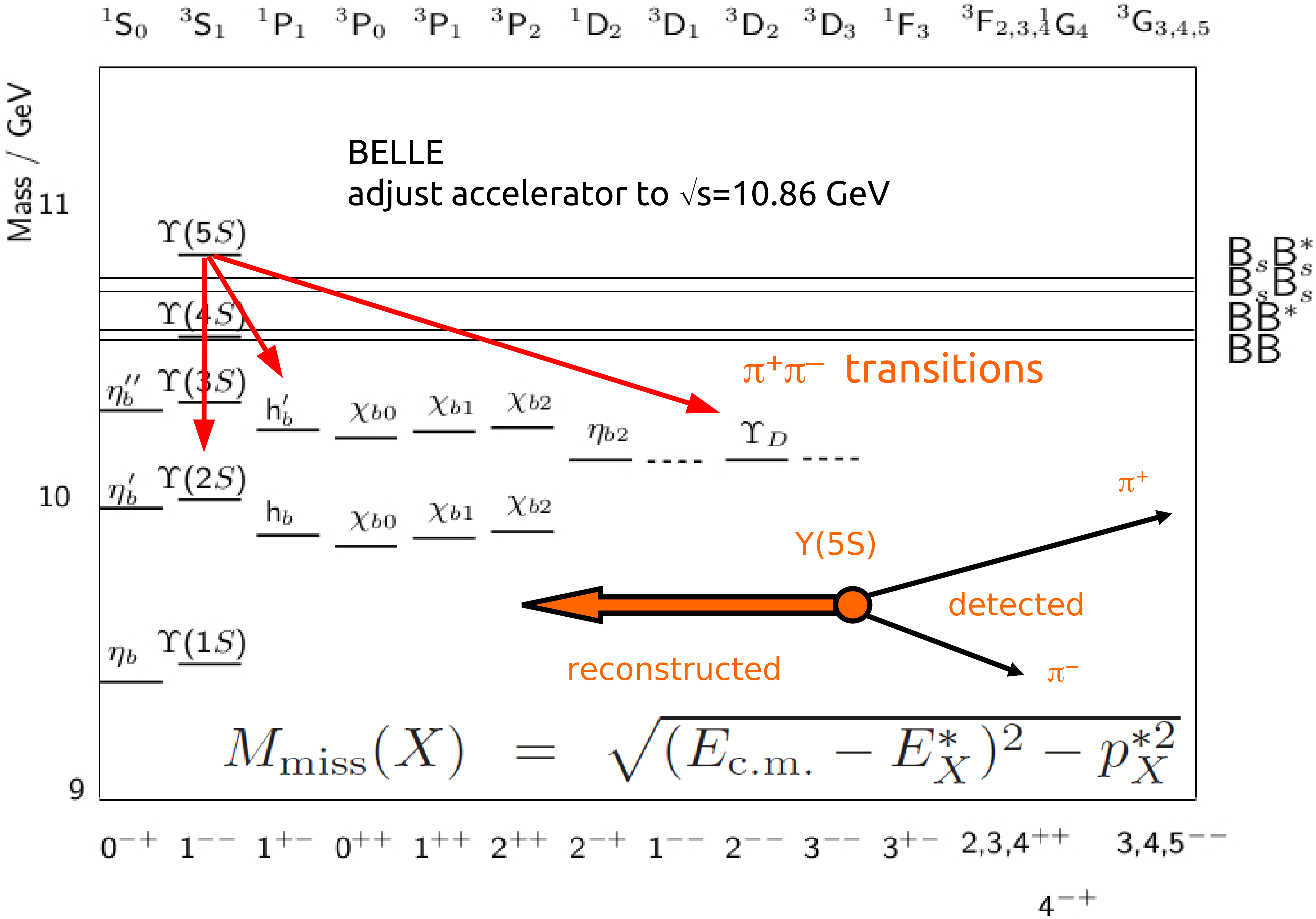
- -Onia program well established at Belle II
  - 50 ab^{-1} for charmonium ISR, double charmonium, $B \to c\bar{c}X$,..
  - 500 fb^{-1} of scan above $\Upsilon(5S)$
  - 300 fb^{-1} of $\Upsilon(3S)$
  - 100 fb^{-1} of $\Upsilon(6S)$ ← Unique case, under discussion
  - 1 ab^{-1} of $\Upsilon(5S)$
- Plan approved since November 2021

  arXiv:1610.01102

  - Planned 50 scan-points around 10.75 GeV
  - 10 fb^{-1} each point (x10 Belle)
  - average beam precision < 1 MeV



BACKUP



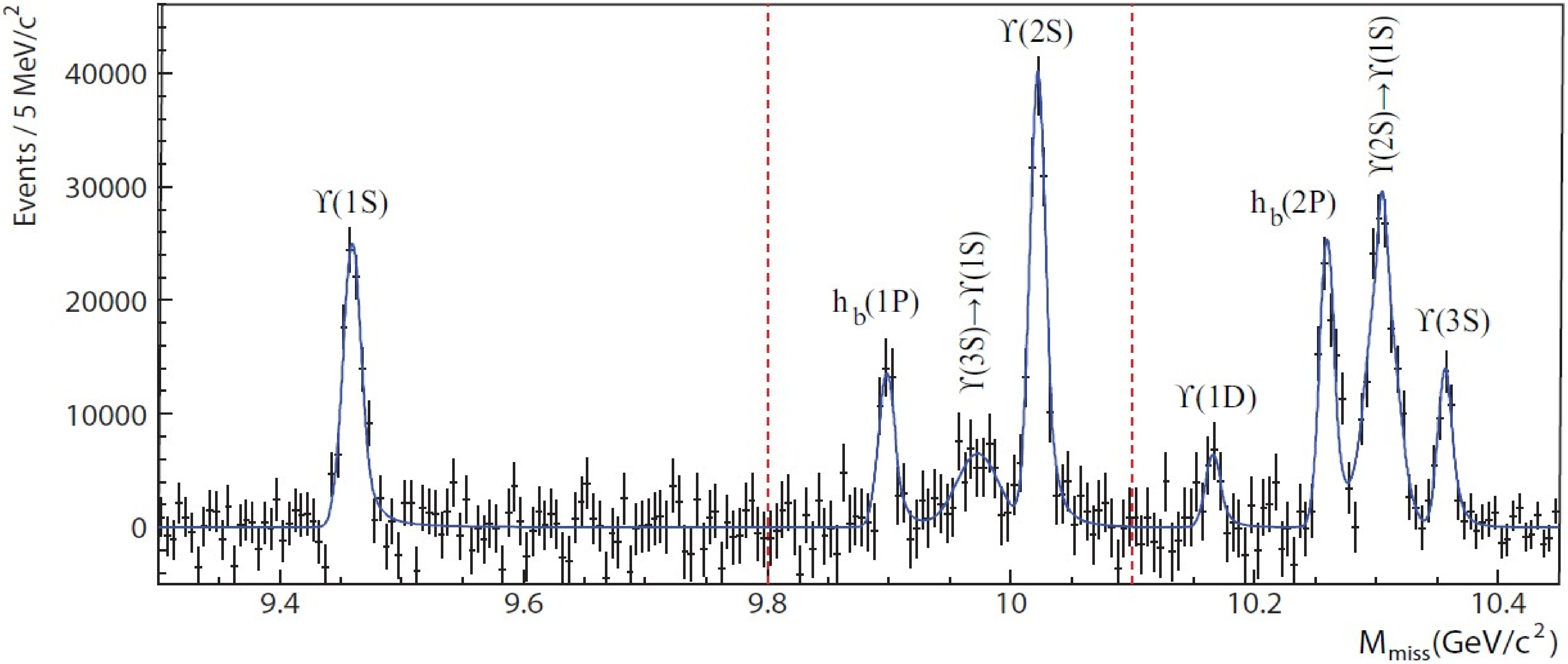
$$M_{\text{miss}}(X) = \sqrt{(E_{\text{c.m.}} - E_X^*)^2 - p_X^{*2}}$$

Υ(5S) Decays

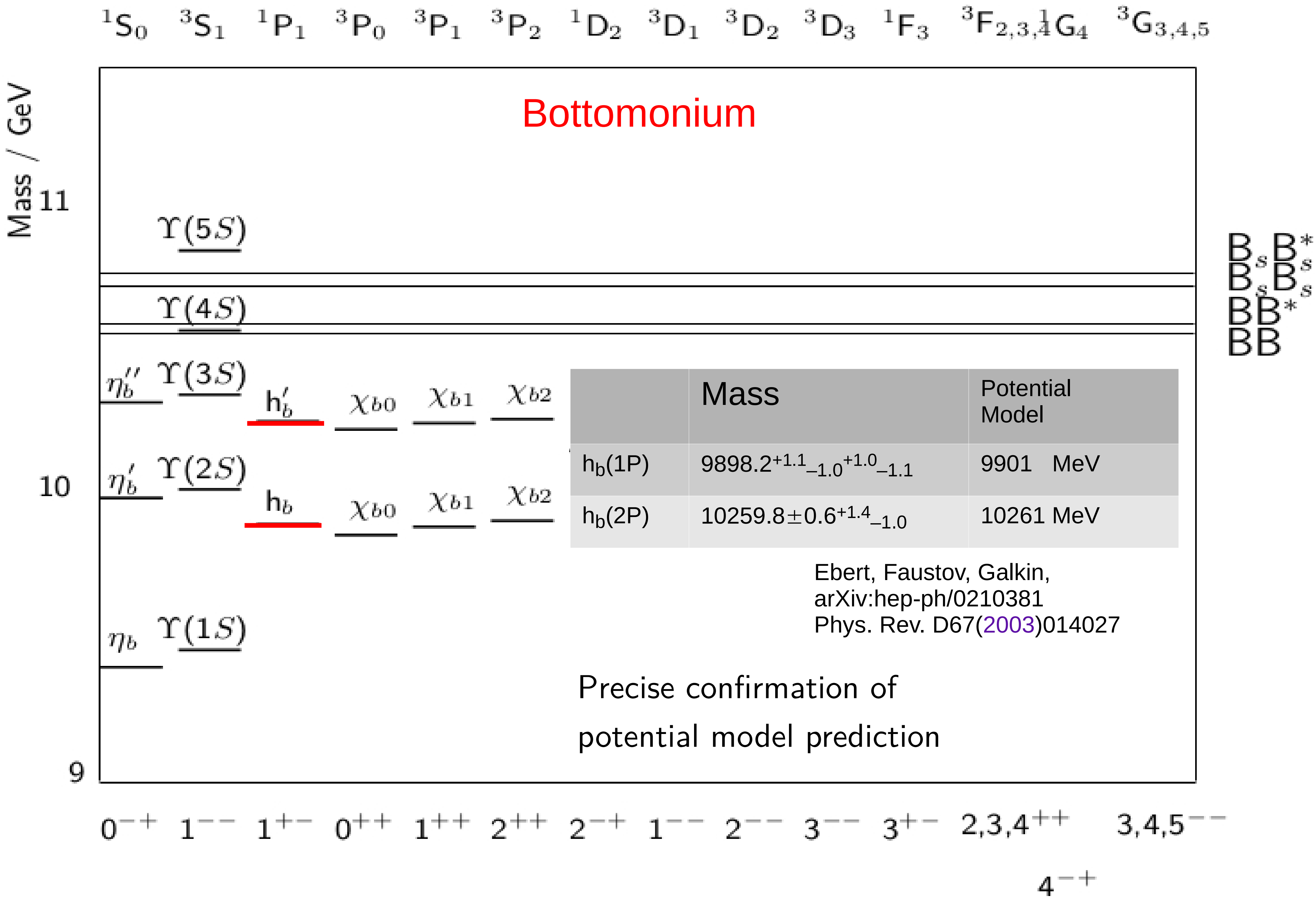
$\pi^+ \pi^-$ missing mass

First observation of
$h_b(1P)$ and $h_b(2P)$

Belle, 121.4 fb^{-1}
Phys. Rev. Lett 108(2011)032001
arXiv:1103.3419



Bottomonium



	Mass	Potential Model
$h_b(1P)$	$9898.2^{+1.1}_{-1.0}{}^{+1.0}_{-1.1}$	9901 MeV
$h_b(2P)$	$10259.8\pm0.6^{+1.4}_{-1.0}$	10261 MeV

Ebert, Faustov, Galkin,
arXiv:hep-ph/0210381
Phys. Rev. D67(2003)014027

Precise confirmation of potential model prediction